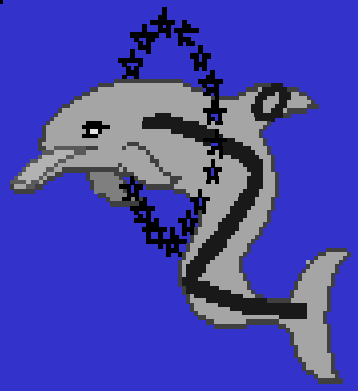
ACCURATE $|V_{cb}|$ MEASUREMENT:

INTEREST OF SPECTRAL MOMENTS



Semileptonic & Rare Decays team

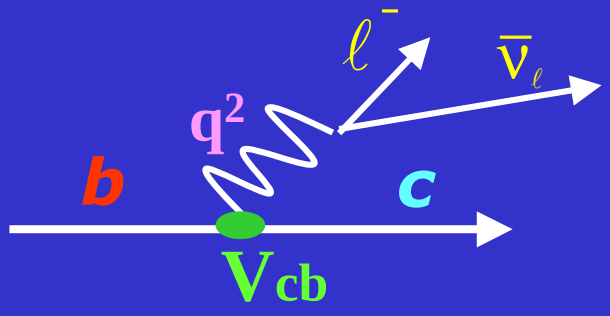
Arantza Oyanguren

September 2002

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

MOTIVATION

$$\text{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



V_{cb} is a fundamental parameter of the flavour mixing matrix

Access from:

Exclusive s.l. decays:
$\bar{B} \to D^{(*)} \ell^- \bar{\nu}_\ell$

ICHEP 2002
DELPHI 2002-074 CONF 608

Inclusive $b \to c \ell^- \bar{\nu}_\ell$:

Two analyses in progress

ICHEP 2002
DELPHI 2002-071 CONF 605
DELPHI 2002-070 CONF 604

ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

MOTIVATION

|Vcb| from inclusive $b \to c\, \ell^- \bar{\nu}_\ell$:

From measured quantities → 1 % accuracy

$$\Gamma_{sl}(b \to c\ell^-\bar{\nu}_\ell) = |V_{cb}|^2 f(theory) = \frac{\mathcal{BR}(b \to c\ell^-\bar{\nu}_\ell)}{\tau_b}$$

Few % accuracy
Evaluated based on *Operator Product Expansion* (OPE)

$c_i = f(m_b, m_c, \alpha_s)$

O.P.E. →

$$\frac{G_F^2 m_b^5}{192\pi^3}\left[c_3\langle B|O_3|B\rangle + c_5\frac{\langle B|O_5|B\rangle}{m_b^2} + c_6\frac{\langle B|O_6|B\rangle}{m_b^3} + \mathcal{O}(1/m_b^4)\right]$$

Non-perturbative corrections

$1+O(1/m_b^2)$

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

THEORY

Two approaches in treating OPE:

- **Pole mass expansion** *(A.F.Falk, M.Luke, …)*
- **Running quark masses** (μ=1GeV) *(M.Voloshin, N.Uraltsev, …)*

$$\frac{G_F^2 m_b^5}{192\pi^3}\left[c_3\langle B|O_3|B\rangle + c_5\frac{\langle B|O_5|B\rangle}{m_b^2} + c_6\frac{\langle B|O_6|B\rangle}{m_b^3} + \mathcal{O}(1/m_b^4)\right]$$

$\overline{\Lambda}$ ~ Energy of light quarks and gluons (related with m_b, m_c)

λ_1 (μ_π^2) ~ Kinetic energy of the b quark inside the meson

λ_2 (μ_G^2) = chromo-magnetic coupling ~ (M_{B^*}-M_B)

λ_1, λ_2
μ_π^2, μ_G^2

ρ_1, ρ_2, $T_{i\ (i=1,4)}$
ρ_D^3, ρ_{LS}^3

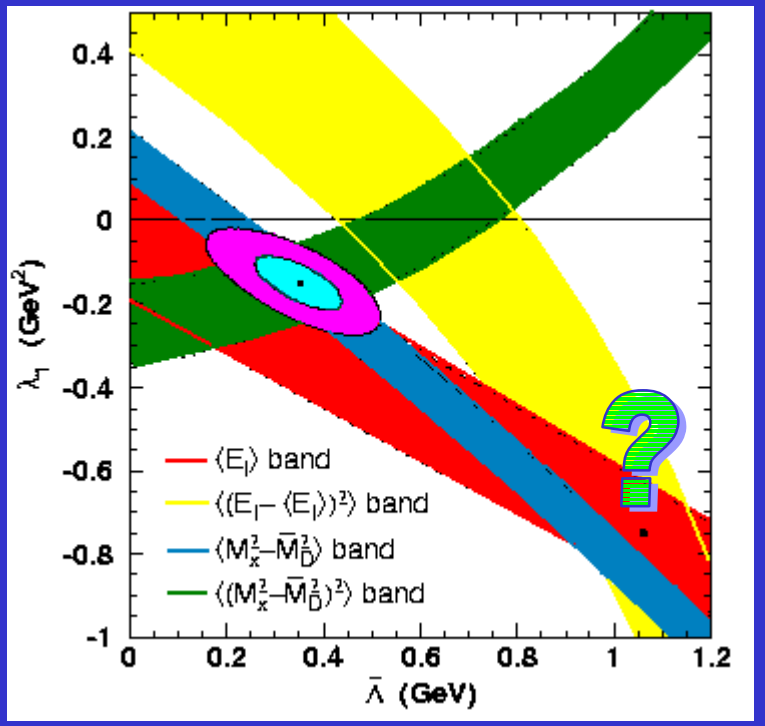
Additional experimental inputs needed to check OPE consistency and improve |Vcb|

Sensitive observables to OPE parameters:

SPECTRAL MOMENTS

$$M_n = \frac{\int \mathcal{O}^n (d\Gamma_{sl}/d\mathcal{O}) d\mathcal{O}}{\int (d\Gamma_{sl}/d\mathcal{O}) d\mathcal{O}}$$

Inclusive Observables $\equiv \mathcal{O} \rightarrow$
Photon* and lepton energies (E_γ, E_ℓ), invariant hadronic mass (M_x), ...



CLEO CONF 98-21

* In $b \rightarrow s\gamma$

ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

|Vcb| MEASUREMENTS

Theory

$\rho_1, \rho_2, T_{i\,(i=1,4)}, \alpha_s(2m_b, m_b/2)$

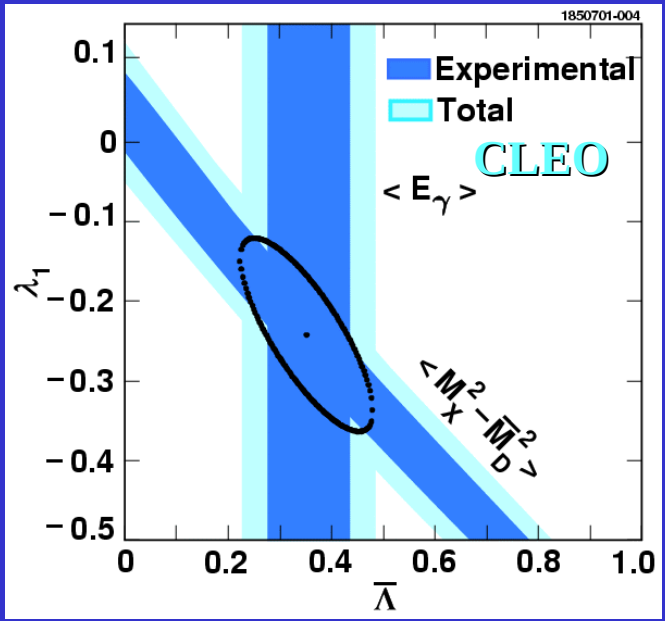
PDG2000 $|Vcb| = (40.8 \pm 0.5 \pm 2.5) \times 10^{-3}$

PDG2002 $|Vcb| = (40.4 \pm 0.5 \pm 0.5 \pm 0.8) \times 10^{-3}$

Exptal.

$\lambda_1, \overline{\Lambda}$

Theoretical expressions at $1/m_b^3, \alpha_s^2$



$\overline{\Lambda}$= =(0.35 ±0.07±0.10) GeV

λ_1=(-0.236 ±0.071±0.078) GeV^2

PRL 87 251807 '01

PRL 87 251808 '01

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

DELPHI MEASUREMENTS

Two analyses on moments:

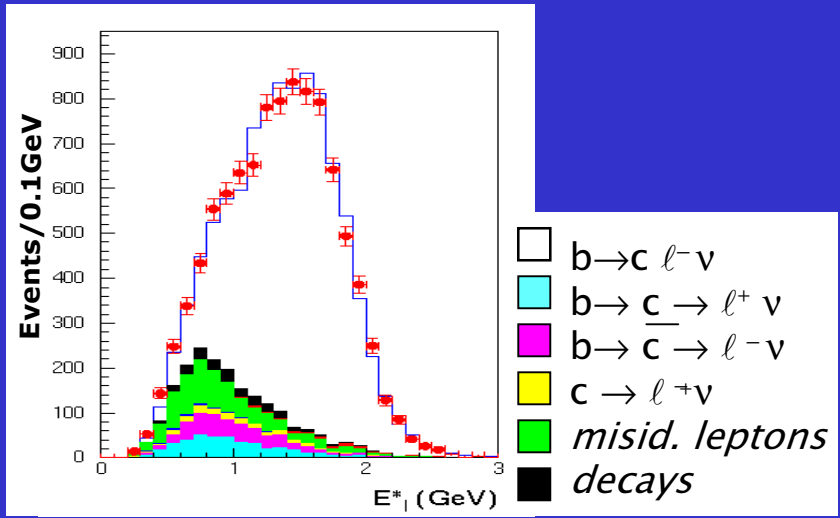
- **MOMENTS OF THE LEPTON ENERGY SPECTRUM**
  - ⇒ Reconstruct the event: $E_B = E_{VERTEX} + E_\ell + E_\nu$
  - ⇒ Reconstruct the B direction
  - ⇒ Boost lepton in B rest frame $\rightarrow E^*_\ell$
  - ⇒ Tag $b \rightarrow X\, \ell^-$ prompt leptons

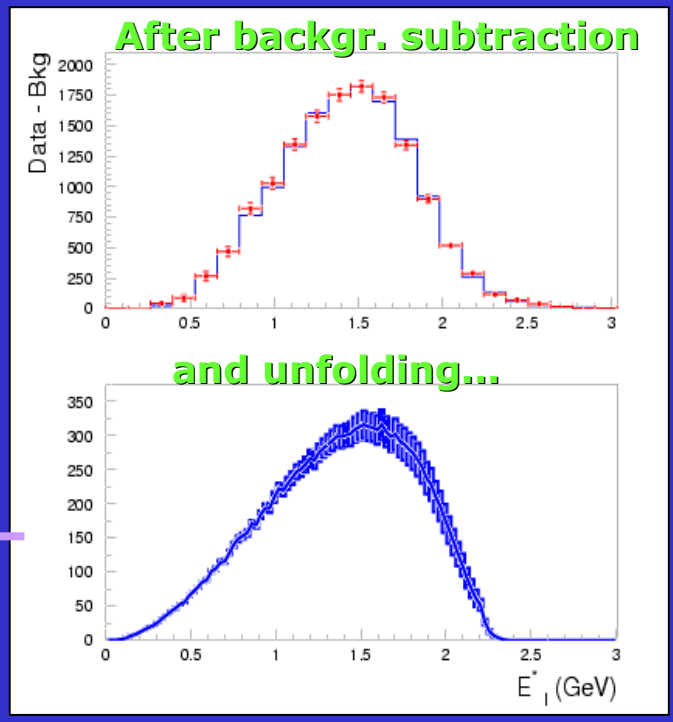
- **MOMENTS OF THE HADRONIC MASS DISTRIBUTION**
  - ⇒ $B \rightarrow D^{**} \ell^- \bar{\nu}_\ell$ exclusively reconstructed by selecting $D^{**} \rightarrow D^0\pi^+, \overline{D^0}\pi^-, D^{\pm}\pi^{\mp}, D^{*\pm}\pi^{\mp}$ + *lepton* candidates
  - ⇒ Fit $\Delta_m = m(D^{(*)}\pi) - m(D^{(*)})$ distributions $\rightarrow \langle m^n_{D^{**}} \rangle$
  - ⇒ $\langle m^n_H \rangle = P_D\, m^n_D + P_{D^*}\, m^n_{D^*} + (1 - P_D - P_{D^*})\, \langle m^n_{D^{**}} \rangle$

ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

MOMENTS OF THE LEPTON ENERGY SPECTRUM

⇒ **Main background reduced using charge correlation and event topology infos**





$\langle E_\ell \rangle = (1.383 \pm 0.012 \pm 0.009)$ GeV

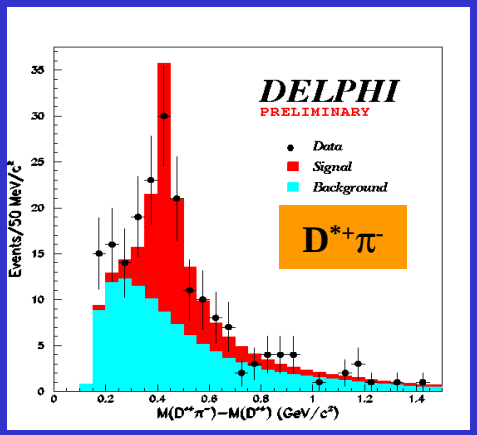
$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle = (0.192 \pm 0.005 \pm 0.008)$ GeV^2

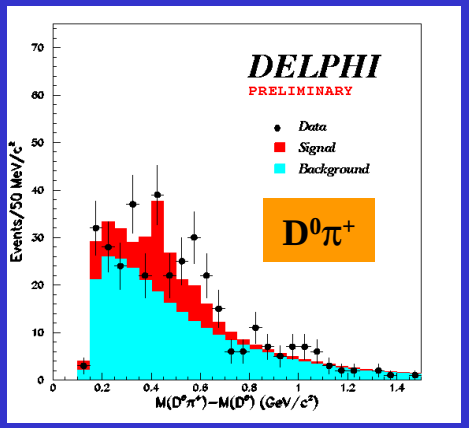
$\langle (E_\ell - \langle E_\ell \rangle)^3 \rangle = (-0.029 \pm 0.005 \pm 0.006)$ GeV^3

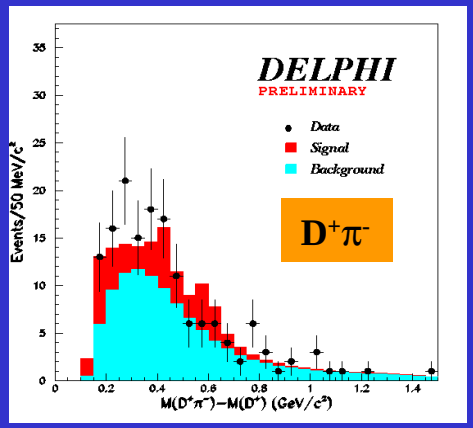
ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

MOMENTS OF THE HADRONIC MASS DISTRIBUTION

Fit Δm distributions including resonant and non-resonant states







$$\langle m^n_H \rangle = p_D\, m^n_D + p_{D^*}\, m^n_{D^*} + (1 - p_D - p_{D^*})\, \langle m^n_{D^{**}} \rangle$$

$M_1 = \langle m^2_H - m^2_D \rangle = 0.534 \pm 0.041 \pm 0.074\ (\mathrm{GeV}/c^2)^2$

$M_2 = \langle (m^2_H - m^2_D)^2 \rangle = 1.51 \pm 0.20 \pm 0.23\ (\mathrm{GeV}/c^2)^4$

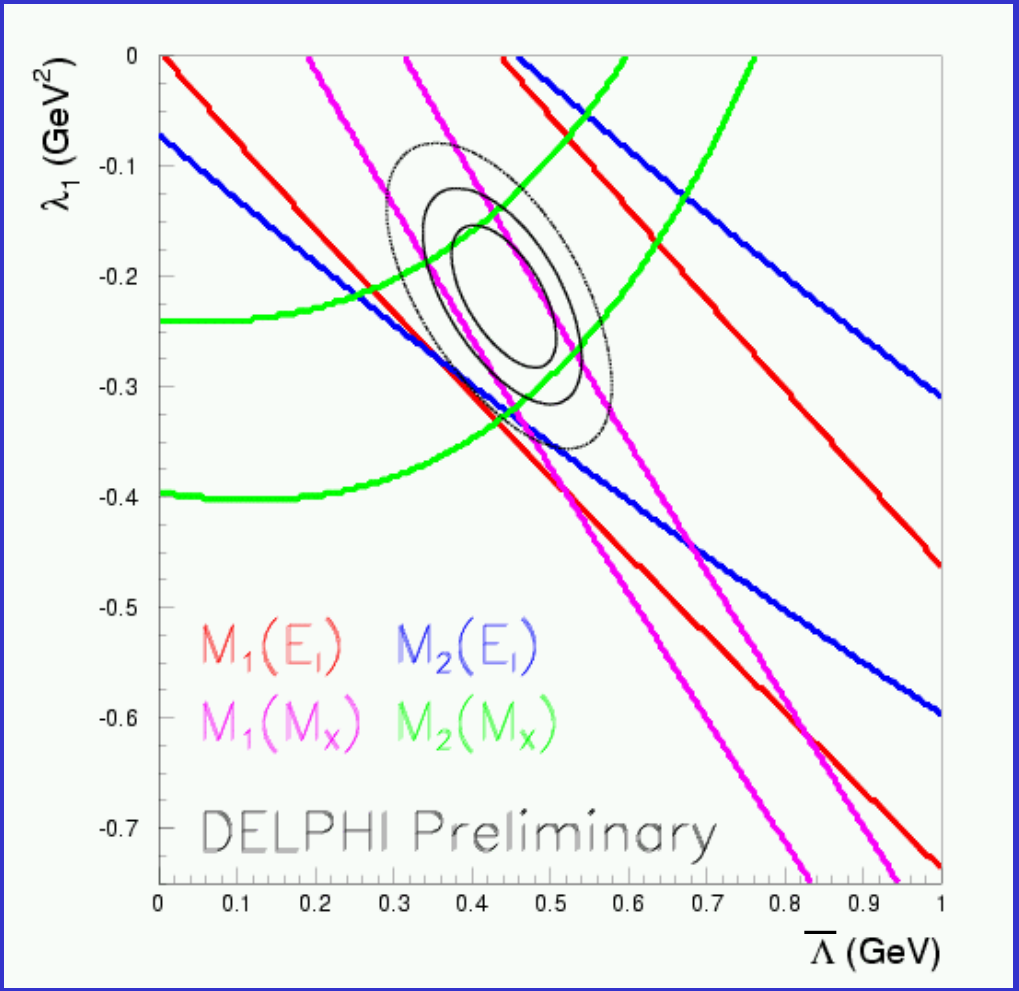
$M_2' = \langle (m^2_H - \langle m^2_H \rangle)^2 \rangle = 1.23 \pm 0.16 \pm 0.15\ (\mathrm{GeV}/c^2)^4$

$M_3' = \langle (m^2_H - \langle m^2_H \rangle)^3 \rangle = 2.97 \pm 0.67 \pm 0.48\ (\mathrm{GeV}/c^2)^6$

ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

PRELIMINARY RESULTS

ICHEP 2002
M. Calvi talk



Pole mass expansion

Constraints on $\overline{\Lambda}$ and λ_1 from the 1st and 2nd hadronic and leptonic moments:

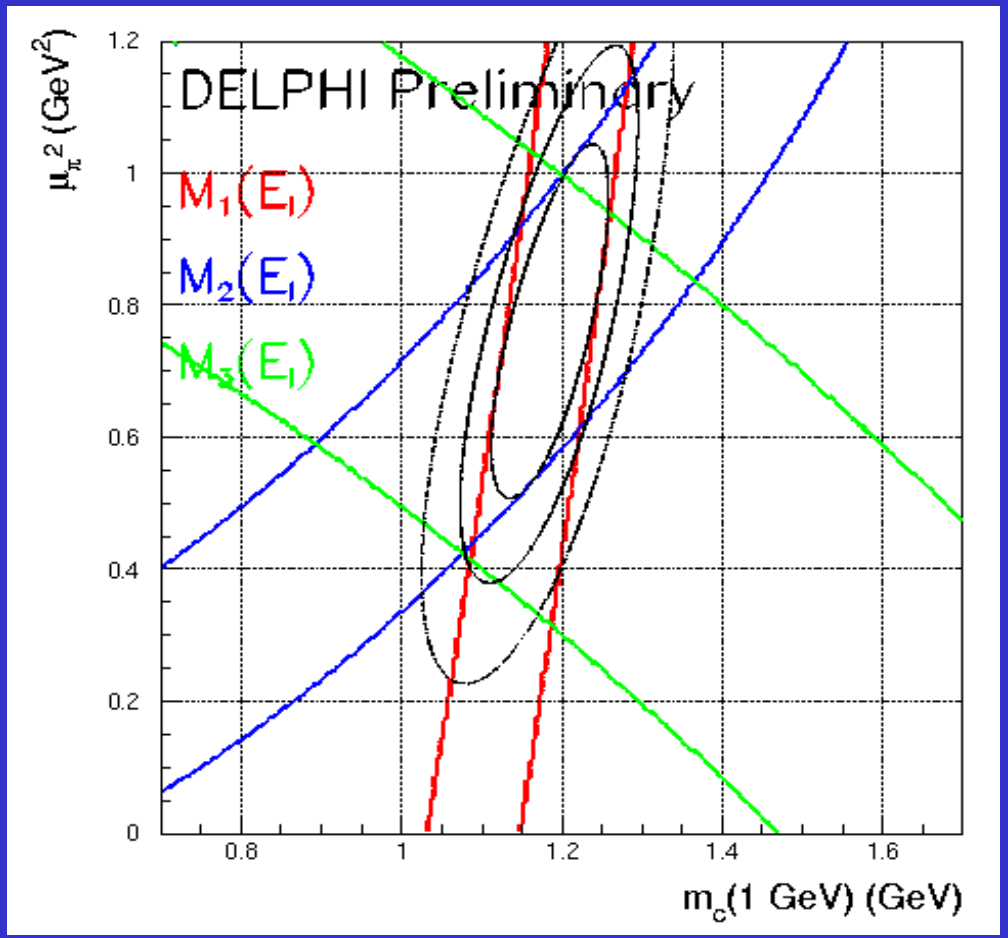
$$\overline{\Lambda} = (0.44 \pm 0.07\ (exp.) \pm 0.07\ (1/m_b^3, \alpha_s))\ \text{GeV}$$

$$\lambda_1 = (-0.23 \pm 0.07\ (exp.) \pm 0.08\ (1/m_b^3, \alpha_s))\ \text{GeV}^2$$

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

PRELIMINARY RESULTS

ICHEP 2002
M. Calvi talk



Running quark masses

Constraints on m_c and μ_π^2

Use the correlation between m_b and m_c:

Fix *b* mass from external measurements:

$m_b = 4.60 \pm 0.05$ GeV

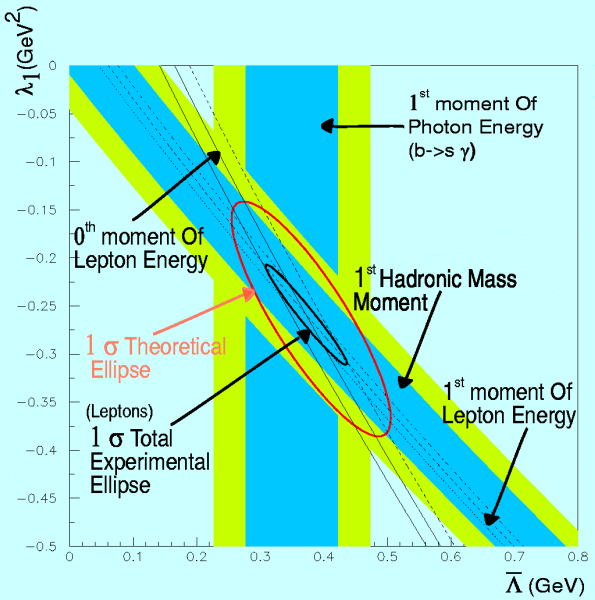
$$m_c(1\text{GeV}) = (\ 1.19 \pm 0.07(\textit{exp.}) \pm 0.07(m_b) \pm 0.04(\rho_D^3)\ )\ \text{GeV}$$

ACCURATE |Vcb| MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

PRELIMINARY RESULTS

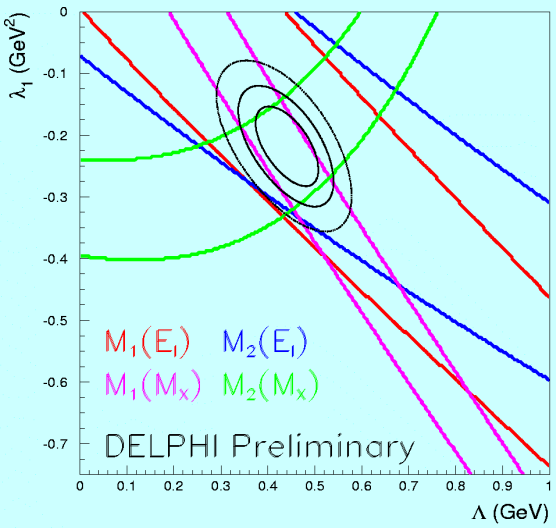
ICHEP 2002
M. Battaglia talk

CLEO PRELIMINARY



$\bar{\Lambda}$=(0.39±.03±.06±.12) GeV
λ_1=(-0.25±.02±.05±.14) GeV^2

DELPHI PRELIMINARY



$\bar{\Lambda}$=(0.44±.04±.05±.07) GeV
λ_1=(-0.23±.04±.05±.08) GeV^2

BABAR PRELIMINARY

From hadronic moments computed with different cuts on the lepton momentum

+

Using the ' 01 CLEO result of

$\bar{\Lambda}$=0.35 ± 0.13 GeV

λ_1=(- 0.17 ±0.06±0.07) GeV^2

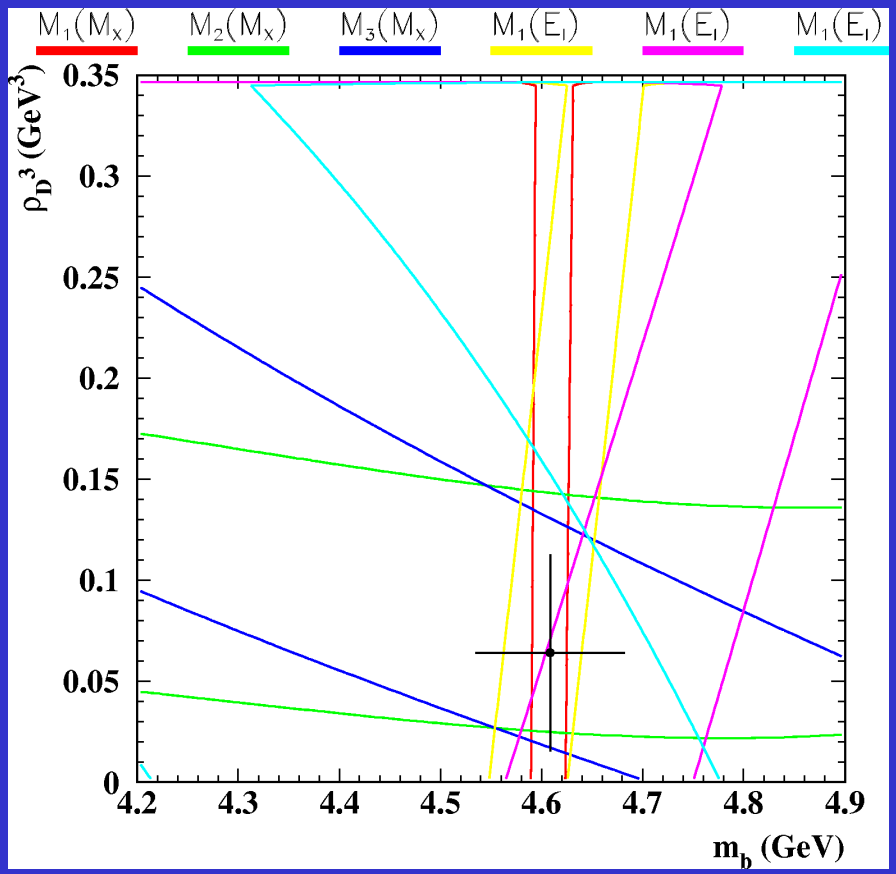
Compatible results from different experiments

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

PRELIMINARY RESULTS

New results including n=3 moments ($1/m_b^3, \alpha_s^2$)

(thanks to N. Uraltsev and P. Gambino)



Running quark masses

4-parameters fit.

Constraints on m_b and m_c:

$m_b = 4.59 \pm 0.09$ GeV

$m_c = 1.17 \pm 0.30$ GeV

$m_{b(1GeV)} = 4.609 \pm 0.074$ GeV

$m_{c\ (1GeV)} = 1.16 \pm 0.12$ GeV

$\mu_\pi^2 = 0.341 \pm 0.062$ GeV^2

$\rho_D^3 = 0.064 \pm 0.049$ GeV^3

ACCURATE $|V_{cb}|$ MEASUREMENT: INTEREST OF SPECTRAL MOMENTS

PERSPECTIVES

Preliminary

$$\frac{|V_{cb}|}{0.04294} = 1 - 0.6577\,(m_b - 4.6\,\text{GeV}) + 0.3932\,(m_c - 1.15\,\text{GeV}) + 0.0128\,(\mu_\pi^2 - 0.4\,\text{GeV}^2)$$
$$+ 0.105\,(\tilde{\rho}_D^3 - 0.12\,\text{GeV}^3) + 0.0591\,(\mu_G^2 - 0.35\,\text{GeV}^2) - 0.0125\,(\rho_{LS}^3 + 0.17\,\text{GeV}^3)$$

$$|Vcb| = (41.7 \pm 0.5 \pm 0.7_{(m_{b,c},\ \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3)}) \pm \sim 0.4_{(\alpha_s)}) \times 10^{-3}$$

- Preliminary errors on $|V_{cb}|$ seem to be < 2% and become of experimental origin
- Still need interactions with theoreticians to clarify the contribution of the different parameters
- Still need to check the validity of theoretical expressions
- Improvement on syst. of hadronic moments expected

ACCURATE $|V_{cb}|$ MEASUREMENT: INTERES OF SPECTRAL MOMENTS

CONCLUSIONS

- **First measurements at LEP of spectral moments**
- **Compatible constraints on the OPE parameters with CLEO and BABAR using different cuts (check OPE consistency)**
- **Aim to a more accurate $|V_{cb}|$ measurement**
  ⟶ theory errors are not anymore dominant